

# OAK ADVANCED REGENERATION FOLLOWING SEASONAL PRESCRIBED FIRES IN MIXED HARDWOOD SHELTERWOOD STANDS<sup>1</sup>

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**Abstract**—Regeneration of oaks (*Quercus*) on productive upland sites is a long-standing silvicultural problem due to aggressive competition from faster growing indeterminant species. We hypothesized that a single prescribed fire 3-5 years after an initial shelterwood cut would increase the competitive position of oak regeneration. Three productive oak-dominated shelterwood stands in the Virginia Piedmont were divided into control, spring-, summer-, and winter-burn treatments. Density and stocking of competitive oaks were greater in burned areas than in the unburned control, especially where medium to high intensity burns occurred during the spring and summer. Oak regeneration was evenly distributed over the burned areas while yellow-poplar (*Liriodendron tulipifera* L.), oak's primary competitor on these sites, occurred in small clumps. Results of this study indicate that areas receiving a single prescribed burn of medium to high intensity during the growing season will develop into oak-dominated stands. Other combinations of fire intensity and season-of-burn will produce mixed hardwood stands with varying proportions of oak.

## INTRODUCTION

Regeneration of oaks on productive upland sites is a long standing problem in the hardwood forest of eastern North America (Beck and Hooper 1986; Pallardy and others 1988; Hix and Lorimer 1991). Harvest of mixed hardwood stands on higher quality mesic sites often results in a shift of species composition favoring non-oak indeterminate hardwoods (Beck and Hooper 1986, Loftis 1983, McGee 1979). Some of the contributing factors to oak regeneration failure are acorn supply, seedling density, insects, disease and animal depredation (Loftis and McGee 1992). The primary cause of oak regeneration failure is thought to be the slow growth of oak reproduction relative to aggressive intolerant species (Beck and Hooper 1986; Johnson and others 1989; Loftis and McGee 1992). In the early years of development, oak regeneration allocates more photosynthate to root development while intolerant species such as yellow-poplar (*Liriodendron tulipifera* L.) allocate more to shoot development (Kolb and others 1990). These differing growth strategies result in oaks being suppressed in the shaded understory while intolerant species move to dominance of the overstory.

If oaks are to be regenerated as the dominant component of a future stand, managers must develop silvicultural prescription to favor oaks. Loftis (1983) found that shelterwood harvests alone would not produce oak-dominated stands. Carvell and Tryon (1961) found that burned areas possess greater reservoirs of oak regeneration. Hannah (1987) suggested prescribed fires as a follow-up treatment for shelterwood harvests.

Johnson and others (1989) proposed that the key to oak regeneration might be competition control rather than long regeneration periods. Sander (1988) stated that multiple understory burns at 2-3 year intervals might be required for effective control of hardwood competition. The frequency of fire is thought to be as important as fire intensity for reduction of fire-susceptible species (De Selm and others 1973).

Recent research indicates that prescribed fire a few years after a shelterwood harvest can enhance the competitive position of oak regeneration (Keyser and others 1996, Brose and Van Lear 1998). Brose and Van Lear (1998) found that oak (*Quercus*) and hickory (*Carya*) regeneration vigorously resprout with improved stem form after such burns while yellow-poplar (*Liriodendron tulipifera*) and other competitors succumbed more easily. This current study is a follow up to Brose and Van Lear's (1998) original study of oak advanced regeneration using a shelterwood cut followed several years later by seasonal prescribed fires. In this study we examined the competitive status of advanced oak regeneration in 1997, three years after the 1995 treatments of seasonal prescribed fires of varying intensities described in Brose and Van Lear (1998). We attempted to define those conditions of fire intensity and timing of burn that would result in adequate free-to-grow oak regeneration in an oak dominated shelterwood stand.

## STUDY SITE

This study was conducted in the Piedmont of central Virginia and located in the Horsepen Wildlife Management Area. This land is owned and managed by the Virginia Department of Game and Inland Fisheries. Topography consists of broad gently-rolling hills between 150 and 180 m elevation. Mean annual precipitation is 110 cm, distributed evenly throughout the year. The average growing season is 190 days. Mean annual temperature for the area is 14°C with a January mean of 4°C and a July mean of 24°C.

The study area consists of three mature oak dominated hardwood sands with a white oak site index 75 (base age 50). The stands are similar in site characteristics and species composition. Overstory trees in the preharvest stand numbered approximately 200/ha, with approximately 75 percent being upland oaks [white oak (*Quercus alba* L.), northern red oak (*Q. rubra* L.), Black oak (*Q. velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.), and chestnut oak (*Q. prinus* L.)]. The remaining 25 percent were yellow-poplar, pignut hickory (*Carya glabra* (Mollier) Sweet), and mockernut hickory (*C. tomentosa* (Poirlet) Nuttall). Common

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midstory hardwoods included red maple (*Acer rubrum* L.), blackgum (*Nyssa sylvatica* Marshall), American beech (*Fagus grandifolia* Ehrhart), American hornbeam (*Carpinus caroliniana* Walter), and sourwood (*Oxydendrum arboreum* L.). There were approximately 2500 stems/ha with most species represented although beech, dogwood, hornbeam, and red maple were most abundant (Brose and Van Lear 1998).

These stands had grown in an undisturbed condition for over 30 years until two of the stands were shelterwood cut in 1990 and the third in 1992 removing 50 percent of each stand overstory. Fifty to 75 dominant oaks and hickory were retained with residual basal areas averaging 13 m<sup>2</sup>/ha. Each stand was previously divided into four 2-5 ha treatment areas and subjected to winter, spring, and summer burns in 1995. One treatment area in each stand was left unburned as a control.

## STUDY DESIGN AND MEASUREMENTS

This study was conducted in a randomized complete block design using the same treatments as Brose and Van Lear (1998) to examine the density, stocking and spatial pattern of oak and yellow-poplar. The design replicates the four treatments: 1) winter burn, 2) spring burn, 3) summer burn, and 4) unburned control in each of the three shelterwood stands. Thirty plots (2.6 m diameter) were systematically located in each treatment area with a plot density of 6-15 plots/ha. We set size and stem form sampling requirements for oak and yellow-poplar because we were interested in the oaks that would have optimal growth and competitiveness.

An acceptable oak had a straight stem and was >1.37 m tall in the control and winter burn treatments, >1.0 m tall in the spring burn treatment, and >0.7 m tall in the summer burn treatment. Sanders and other (1976) showed that oak regeneration must be >1.37 m tall to be competitive after release. Our height specifications vary as a result of differences in the amount of growing time due to seasons of burning. An acceptable yellow-poplar was at least half the required oak height for the treatment (0.7, 0.5, and 0.35 m tall in winter and control, spring, and summer treatments, respectively). These height requirements were allocated because of yellow-poplar's ability to outgrow oak on these sites (Beck and Hooper 1986, Johnson and other 1989).

Densities (stems/ha) were obtained by counting all acceptable oak and yellow-poplar stems in each plot. Stocking of oak and yellow-poplar was measured by determining the proportion of plots containing an acceptable representative. The T-square sampling method was used to determine the spatial pattern of oaks and yellow-poplar in the treatment area (Ludwig and Reynolds 1988). An index was calculated separately for oak and yellow-poplar using distance measurements ( $\pm 0.1$  m) from plot center to nearest species and then to next nearest species to determine if regeneration was clustered, random, or uniformly distributed.

Competition of the present advance oak regeneration was measured in the different treatment areas. We examined these inter-species spatial relations using a modified Heygi competition index (Clinton and others 1997). The largest most competitive oak was visually selected and its height recorded. Heights of all competitors and their distance from

selected oak were measured within a 3-m radius of the target oak. These measurements were used to calculate a competition value.

A competitor was defined as a yellow-poplar seedling at least half the height of the oak located within a 1.5-m radius of the oak and any yellow-poplar stump sprout within a 4.5-m radius. A competitor will also be any of the following species that are of equal or greater height and within a 3-m radius of the oak: hickory, cherry (*Prunus serotina* Ehrhart), sweetgum (*Liquidambar styraciflua* L.), yellow-poplar, loblolly pine (*Pinus taeda* L.), ash (*Fraxinus* L.), locust (*Robinia* L.), and red maple stump sprouts with a 2 inch or greater ground-line diameter. Species that only occupy midstory upon maturity such as blackgum, flowering dogwood, and hornbeam, were not considered major competitors because oak will eventually surpass them. (Nix 1989, Waldrop 1997).

A 3-m radius was used because it corresponded to Heygi's index and provides at least 50 percent of the growing space needed at maturity for the target oak. Target oaks with no competitors were considered free-to-grow (Nix 1989).

Due to varying fire intensities within treatments (Brose and Van Lear 1998), plots in the burned treatment areas were assigned to one of four levels of fire intensity. Fire intensities were based on fuel consumption during the prescribed burns. Brose (1997) documented fire behavior, fire intensity, and changes in fuel loading within each treatment area as follows. Low-intensity fires (flame lengths <0.3 m) partially consumed litter and small woody debris (<0.8 cm diameter), and top-killed <75 percent of the advanced regeneration. Low-medium-intensity fire (flame lengths between 0.3 and 0.75 m) completely consumed litter and small fuels and top-killed 75-100 percent of the regeneration. Medium-high-intensity fire (flame length 0.75-1.2 m) top-killed all regeneration, visibly reduced loading of 2.5-7.5 cm diameter fuels, caused approximately 50 percent mortality of midstory trees, and scorched bark on occasional overstory trees. High-intensity fire (flame lengths >1.2 m) visibly reduced woody debris >7.5 cm diameter, killed most midstory trees, charred bark on most overstory trees, and caused occasional mortality of an overstory tree. A 3x4 factorial design, with three fire seasons and four fire intensity levels, was used to examine the effects of different fire-intensity levels.

## STATISTICAL ANALYSIS

Analysis of variance with Student-Newman-Kuel mean separation test was used to compare season-of-burn treatments for differences in density and clustering of oak and yellow-poplar regeneration (SAS Institute 1993). Competitive condition of oak was tested with analysis of covariance and least-squares mean separation with regeneration age as the covariate (SAS Institute 1993). Analysis of variance with least-squares mean separation was used to test for differences among these variables as fire intensity interacted with season-of-burn (SAS Institute 1993). Chi-square analysis was used to compare differences in stocking among treatments and among fire intensities within season-of-burn (SAS Institute 1993). In all tests,  $\alpha=0.05$  and data were rank-transformed as needed to correct unequal variances and non-normality of residual values.

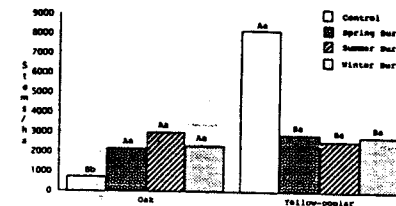


Figure 1—Density of oak and yellow-poplar advanced regeneration after seasonal prescribed fires in shelterwood stands in the Virginia Piedmont. Bars with different uppercase letters are different for that species ( $\alpha=0.05$ ). Bars with different lowercase letters are different for that treatment ( $\alpha=0.05$ ).

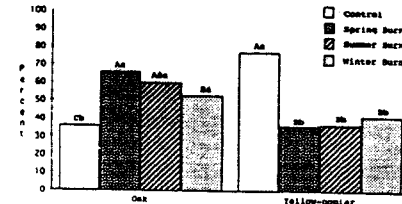


Figure 2—Stocking of oak and yellow-poplar advance regeneration after seasonal prescribed fires in shelterwood stands in the Virginia Piedmont. Bars with different uppercase letters are different for that species ( $\alpha=0.05$ ). Bars with different lowercase letters are different for that treatment ( $\alpha=0.05$ ).

## RESULTS

### Density

Oak density was significantly greater in the burn treatments with three times as many oak stems (fig. 1). The burned treatments had half as many yellow-poplar as the unburned control. In the burned areas yellow-poplar and oak had equivalent densities while in the unburned control yellow-poplar out-numbered oak 8:1.

Oaks were most abundant in high intensity spring and low-to-medium intensity summer burns (Table 1). Yellow-poplar had significantly higher densities in the low intensity areas of all seasons of burn, especially in the winter burn. Oak and yellow-poplar density were equivalent in the medium intensity areas while oak was significantly greater in high intensity fires.

Table 1—Density (mean stems/ha  $\pm$  1 se) of oak and yellow-poplar regeneration after four different levels of fire intensity in the Virginia Piedmont

Species	Fire intensity levels			
	Low	Low medium	Medium high	High
Spring burn				
Oak	1694 $\pm$ 600C <sup>a,b</sup>	1709 $\pm$ 571B <sup>a,b</sup>	2385 $\pm$ 571AB <sup>a,b</sup>	4180 $\pm$ 511A <sup>a,b</sup>
Yellow-poplar	5567 $\pm$ 1887AB <sup>a,b</sup>	2776 $\pm$ 682B <sup>a,b</sup>	3685 $\pm$ 1047A <sup>a,b</sup>	1134 $\pm$ 699C <sup>b,b</sup>
Summer burn				
Oak	2724 $\pm$ 813BC <sup>a,b</sup>	4945 $\pm$ 1077A <sup>a,b</sup>	2043 $\pm$ 701AB <sup>a,b</sup>	2389 $\pm$ 499B <sup>a,b</sup>
Yellow-poplar	4051 $\pm$ 1037B <sup>a,b</sup>	3631 $\pm$ 1158AB <sup>a</sup>	1134 $\pm$ 921B <sup>a,b</sup>	573 $\pm$ 131C <sup>b,b</sup>
Winter burn				
Oak	2006 $\pm$ 737C <sup>a,b</sup>	1955 $\pm$ 436B <sup>a,b</sup>	1961 $\pm$ 538AB <sup>a,b</sup>	3111 $\pm$ 402B <sup>a,b</sup>
Yellow-poplar	9077 $\pm$ 2418A <sup>a,b</sup>	2823 $\pm$ 714AB <sup>a,b</sup>	1470 $\pm$ 647B <sup>b,c</sup>	865 $\pm$ 694C <sup>c,c</sup>

<sup>a</sup> Means with different uppercase letters are different within that column ( $\alpha = 0.05$ ).

<sup>b</sup> Means with different lowercase letters are different within that row ( $\alpha = 0.05$ ).

Table 2—Stocking percent (mean  $\pm$  1 se) of oak and yellow-poplar regeneration after four different levels of fire intensity in the Virginia Piedmont

Species	Fire intensity levels			
	Low	Low medium	Medium high	High
Spring burn				
Oak	64 $\pm$ 25AB <sup>a</sup> ab <sup>b</sup>	63 $\pm$ 13AB <sup>a</sup> ab <sup>b</sup>	53 $\pm$ 9Bb	48 $\pm$ 15Aa
Yellow-poplar	83 $\pm$ 27AB <sup>a</sup> a <sup>b</sup>	58 $\pm$ 16AB <sup>a</sup> ab <sup>b</sup>	44 $\pm$ 10B <sup>a</sup> ab <sup>b</sup>	21 $\pm$ 15CD <sup>a</sup> b <sup>b</sup>
Summer burn				
Oak	54 $\pm$ 8B <sup>a</sup> b <sup>b</sup>	79 $\pm$ 11A <sup>a</sup> a <sup>b</sup>	56 $\pm$ 18B <sup>a</sup> b <sup>b</sup>	42 $\pm$ 20BC <sup>a</sup> b <sup>b</sup>
Yellow-poplar	72 $\pm$ 12B <sup>a</sup> a <sup>b</sup>	45 $\pm$ 12B <sup>a</sup> a <sup>b</sup>	13 $\pm$ D <sup>b</sup> b <sup>b</sup>	10 $\pm$ 10D <sup>b</sup> b <sup>b</sup>
Winter burn				
Oak	50 $\pm$ 8B <sup>a</sup> b <sup>b</sup>	47 $\pm$ 11B <sup>a</sup> b <sup>b</sup>	67 $\pm$ 5A <sup>a</sup> a <sup>b</sup>	52 $\pm$ 14B <sup>a</sup> b <sup>b</sup>
Yellow-poplar	92 $\pm$ 8A <sup>a</sup> a <sup>b</sup>	56 $\pm$ 6B <sup>a</sup> b <sup>b</sup>	49 $\pm$ 5C <sup>a</sup> c <sup>b</sup>	14 $\pm$ 14D <sup>a</sup> c <sup>b</sup>

<sup>a</sup> Means with different uppercase letters are different within that column ( $\alpha = 0.05$ ).  
<sup>b</sup> Means with different lowercase letters are different within that row ( $\alpha = 0.05$ )

#### Intra-Species Spatial Pattern

The spatial arrangement of oak and yellow poplar regeneration differed from each other in all the treatments. The oaks scored between 0.27-0.39 on a 0-1 spatial index indicating that oak regeneration was uniformly distributed over all treatments. Yellow-poplar scored between 0.64-0.73 indicating that yellow-poplar regeneration was clustered. The spatial patterns within species were not affected by treatments or fire intensities.

#### Intra-species Competitive Relationship

Oaks in the burn treatments had significantly lower competition (Hegyi index=0.24) than oak in the unburned control (index=0.35) (Table 3). The number of competitors was highest in unburned control and lowest in the spring and summer burn treatments. Distance to nearest non-oak

competitors was also significantly closer in the unburned treatment than in the burned treatments. There was no difference in competition between seasons of burn. As fire intensity increased within the burned treatments density of competitors decreased.

There were significantly more free-to-grow oak in the spring and summer burn treatments (425 and 363 stems/ha, respectively) than in the winter burn and unburned control (82 and 141 stems/ha, respectively) (fig. 3). The high intensity spring burn areas (832 stems/ha) had the most free-to-grow oaks. The medium intensity summer burn areas (551 and 453 stems/ha) had the next largest quantity of free-to-grow oak followed by the medium intensity spring fires (321 and 373 stems/ha). Free-to-grow oaks were nearly absent in the low intensity spring and winter burn areas with

Table 3—Competitive status (mean  $\pm$  1 se) of oaks 3 years after seasonal prescribed fires in shelterwood stands in the Virginia Piedmont

Treatment	Oak height	Number of competitors	Competitor height	Distance to nearest competitor	Hegyi competition index
	m	Stems/plot	m	m	
Control	2.4 $\pm$ 1A <sup>a</sup> b <sup>b</sup>	7.6 $\pm$ 0.8A <sup>a</sup>	2.9 $\pm$ 0.1A <sup>a</sup> a <sup>b</sup>	0.8 $\pm$ 0.1B <sup>a</sup>	0.35A <sup>a</sup>
Spring burn	1.6 $\pm$ 1C <sup>a</sup> b <sup>b</sup>	5.3 $\pm$ 0.3C <sup>a</sup>	2.0 $\pm$ 0.1C <sup>a</sup> a <sup>b</sup>	1.3 $\pm$ 0.1A <sup>a</sup>	.25B <sup>a</sup>
Summer burn	1.1 $\pm$ 1D <sup>a</sup> b <sup>b</sup>	4.7 $\pm$ 0.3C <sup>a</sup>	1.5 $\pm$ 1.0D <sup>a</sup> a <sup>b</sup>	1.3 $\pm$ 0.1A <sup>a</sup>	.23B <sup>a</sup>
Winter burn	1.9 $\pm$ 1B <sup>a</sup> b <sup>b</sup>	6.0 $\pm$ 0.1B <sup>a</sup>	2.5 $\pm$ 0.1B <sup>a</sup> a <sup>b</sup>	1.2 $\pm$ 0.1A <sup>a</sup>	.25B <sup>a</sup>

<sup>a</sup> Means followed by different uppercase letters are different within that column ( $\alpha = 0.05$ ).  
<sup>b</sup> Height means followed by different lowercase letters are different from each other within that row ( $\alpha = 0.05$ ).

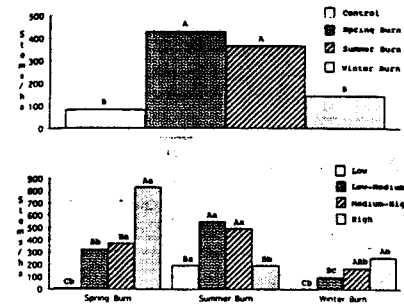


Figure 3—Density of free-to-grow oaks among treatments and among fire intensity levels within season-of-burn in shelterwood stands in the Virginia Piedmont. Bars with different uppercase letters are different for that species ( $\alpha=0.05$ ). Bars with different lowercase letters are different for that treatment ( $\alpha=0.05$ ).

less than 5 stems/ha. There were 101 and 173 stems/ha in the medium intensity winter burn areas and 259 stems/ha in the high intensity winter areas.

Stocking of free-to-grow oak were higher in the spring and summer burn (24 and 20 percent, respectively) than in the winter burn and control (8 and 4 percent, respectively) (fig. 4). The high intensity spring burn areas had the highest stocking (46 percent) while the low intensity area in the spring and winter burn had the lowest stocking (1 percent). The two medium and high intensity burn areas in the summer burn had equivalent stocking.

#### DISCUSSION

Disturbance of the stand and increased lighting of the forest floor after shelterwood harvest results in tremendous numbers of yellow-poplar. Preburn densities of yellow-poplar in our study area reached 10,000 stems/ha while oak was around 2,000 stems/ha in all treatments (Brose and Van Lear 1998). Yellow-poplar seed banks can remain viable in the forest floor up to seven years (Beck 1981) and profusely germinate upon disturbance.

Prescribed fire drastically reduced the density and stocking of yellow-poplar in all burn treatments while increasing that of oak. Burning reduced competition in the stand and resulted in smaller clusters of yellow-poplar.

Acorns are usually buried by animals and have hypogeal germination (cotyledons remain in seed) which places the root collar and its dormant buds below the surface. Yellow-poplar seeds have epigeal germination, generally placing the root collar and its accompanying dormant buds above the soil surface (Beck 1981). This difference in germination strategy makes yellow-poplar more susceptible to lethal temperatures at or above ground level. Oaks also allocate more carbon to development of a large tap root in their early

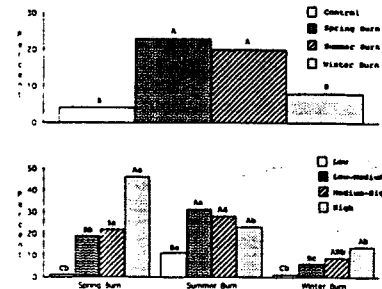


Figure 4—Stocking of free-to-grow oaks among treatments and among fire intensity levels within season-of-burn in shelterwood stands in the Virginia Piedmont. Bars with different uppercase letters are different for that species ( $\alpha=0.05$ ). Bars with different lowercase letters are different for that treatment ( $\alpha=0.05$ ).

years while yellow-poplar allocates carbon to stem growth. This difference in growth strategy gives oak a more favorable root/shoot ratio for vigorous resprouting after being top killed by fire.

Fire intensity, season of burn, and varying growth strategies, affect the composition of regeneration. Medium to high intensity growing season burns resulted in lower densities and stocking of yellow-poplar with abundant free-to-grow oaks and reasonable stocking.

#### CONCLUSION

Oaks were adequately stocked in burned areas. However, free-to-grow oaks were only adequately stocked in medium-high to high intensity burned areas in the spring burn. The number of yellow-poplar saplings were greatly reduced by burning and were in smaller clusters while oaks were uniformly distributed over the stands. Competition of oak is also lower in burned areas and decreases as fire intensity increases. We recommend a medium-high to high intensity burn a few years after the initial shelterwood cut to regenerate oak on productive upland sites. If the fire intensity is not maintained at a consistent medium-high to high intensity level then a second burn will likely be required. Otherwise, a mixed hardwood stand with varying proportions of oak will develop.

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